Automated Measurement of Frequency Response of Electrical Networks, Filters and Amplifiers

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Abstract:

This paper describes the design, operation and use of a PC controlled automated frequency response measurement system using the standard bench-top test equipment available in undergraduate electronics laboratories. The system described employs the waveform data acquisition and processing capabilities of digital oscilloscopes to extract amplitudes (rms or peak), periods, frequencies and relative time delays of waveforms measured at the input and output terminals of a circuit under test. In combination with GPIB control of oscilloscope settings and the frequency of a signal generator, full automation of the frequency response measurement is achieved in a cost-effective manner by using a LabView code developed. The frequency range is of the current system is 12mHz to 12MHz, more than needed for most electronic/acoustic and electromechanical systems frequency tests, and can be expanded by employing a signal generator with higher frequency range. Frequency response measurements are not unique to electronic circuits, amplifiers and filters. The measurement system described here can easily be adapted to determine the frequency response of mechanical, acoustical and other electromechanical and nonelectrical systems as long as appropriate transducers/sensors are introduced to do the required conversions from electrical to non-electrical quantities and vice versa.

Being a much faster alternative to manual measurements, such automated measurements meet a need recently created by the heavy emphasis put on "design" in the electronics curriculum. In the design of analog electronic circuits, in particular those requiring a narrow range of specifications to be met, the cycle time of the test has become a critical factor in fitting a large number of redesign-and-test iterations into a time-limited laboratory session.

1. Introduction

This paper describes the design, operation and use of a PC controlled automated frequency response measurement system using the standard bench-top test equipment available in undergraduate electronics laboratories. Being a much faster alternative to manual measurements, such automated measurements meet a need recently created by the heavy emphasis put on "design" in the electronics curriculum, in particular, in the design of analog circuits requiring a high degree of precision to be achieved. In the implementation of such high precision circuit designs, it is not possible to hit all of the design specifications with high degree of precision even though well established design procedures and codes that convert these procedures into a MathCad, Mathematica, MathLab, C file for automated design may have already been developed and used. Ultimately, the design will be put on breadboard and tested against the design specifications, if failing to meet the specifications within their allowed range or "window", the design has to be redone by either restarting from scratch, or more often, by an iterative method of tweaking on some circuit parameters, and testing the new circuit, and repeating these steps in a series of iterations until all of the targets are hit. The higher the required level of precision in the design specifications (or, the narrower the window of tolerance) the larger the number of the iterations, (i.e. design + simulate + verify + protoboard + test + if not passing redesign or modify + test +…repeat) are needed, therefore forcing a quick turn around time for testing in order to fit such design experiments into the limited hours of a weekly laboratory schedule.

2. The Measurement System

The automated frequency measurement system reported here employs a standard set of bench-top instruments consisting of a Hewlett Packard Digitizing Oscilloscope (Model 54501A), a Tektronix Arbitrary Function Generator (AFG 5101), a Tektronix Programmable Digital Multimeter (DM 5120) , and a Tektronix Triple Power Supply (PS 250). Except the power supply which is manually controlled, all of the other instruments are equipped with GPIB interface. A Pentium II computer equipped with National Instrument's IEEE488.2 card controls the setup. A system schematic of the measurement setup is given in Figure 1. The same setup is also employed for the automated measurement of I-V and C-V characteristics of semiconductor devices and sensors and, to extract SPICE parameters from them in our student laboratories at the University of Southern Maine. (see Guvench [1] and [4]).

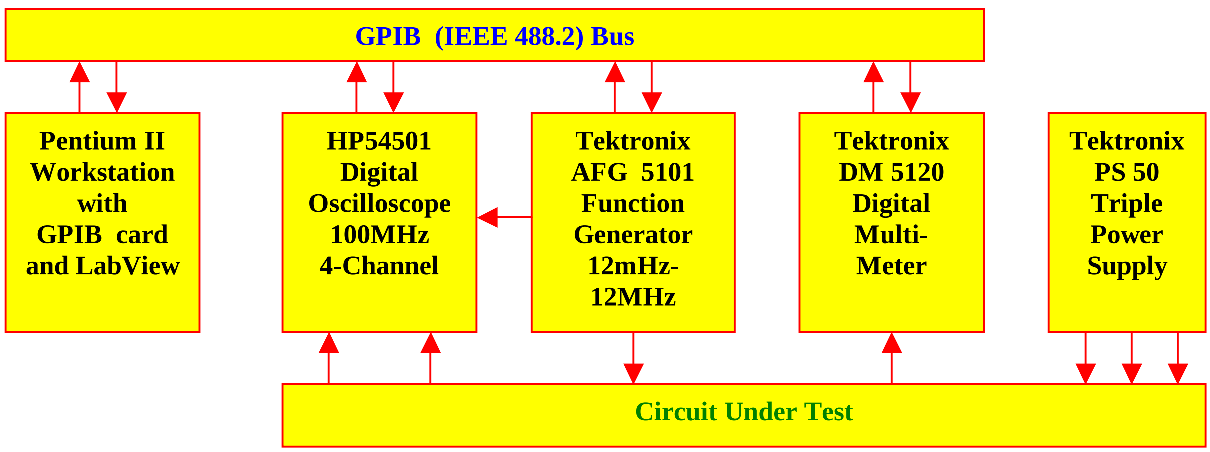

Figure 1. System Schematic

In the frequency response measurements of a circuit magnitudes and the relative phase of a signal applied to the input and the voltage appearing at its output of a circuit have to be measured. To measure a frequency response, the signal frequency has to be stepped, the measurement being repeated at every step to gather data points to plot the response as a function of frequency. Input and output voltage amplitude measurements can be accomplished very simply by employing two AC voltmeters. However, most undergraduate teaching laboratories are equipped with only one meter per station. Beams [3] has shown that with external circuitry controlled by a PC, one can multiplex the input and the output signals into a single voltmeter. He has cleverly designed a I-Q phase detector and incorporated it with his multiplexer to do both phase and amplitude measurement with only one digital multimeter. However, the frequency was limited by the phase detector to only two decades of dynamic range and to a maximum value of 100KHz.

In our system we employ the digital oscilloscope of the set up rather than the multimeter. The following is a list of the advantages of our system over the ones employing multimeters. Unlike the digital multimeter, the oscilloscope (1) provides multiple channels, thus eliminating the need for multiplexing, (2) has three orders of magnitude higher frequency bandwidth and covers DC through 100MHz, (3) displays actual waveforms, showing distortions, noise and oscillations in real time without hiding or averaging them into the signal's amplitude, and, (4) can be triggered externally for time delay (phase) measurements between the channels. In addition, from the waveforms displayed one can measure and verify the frequency of the signal. However, autoscaling of the time base and the vertical sensitivities of the channels and, extraction of amplitude, frequency and phase from the displayed waveforms become challenging difficulties.

In the earlier generation of the system, "Bode-3" a compiled Quick Basic program was developed to control and step the signal generator, to autoscale the oscilloscope and to measure and extract frequency, amplitude, phase delay data and to create a text file for use with a spreadsheet program. In the second generation of the system reported here National Instruments' LabView is being employed (1) to facilitate a user friendly graphical interface, (2) to create virtual instruments and, (3) to plot the frequency response on the screen while taking data. The new "Bode-99" LabView program developed also creates data files that can be processed and plotted in Excel.

For "Bode-99" to work properly, oscilloscope's Channel-1 and Channel-4 inputs should be connected to the input and output terminals of the circuit under test, respectively. These are the two 8-bit resolution fully controlled inputs of the HP 54501. Channels 2 and 3 have limited scaling range, therefore are used for external edge-triggering of the oscilloscope via a BNC connection between TTL compatible SYNC-OUT of the signal generator and Channel-2. This triggering connection is essential for any time delay measurement (phase angle) by tying both Ch-1 and Ch-2 to the same reference in time irrespective of the vertical mode of operation of the scope, whether it be alternate or chopped. It is prudent and recommended practice that an automated measurement be preceded by a manual setting of the instruments in which (1) the signal generator's frequency is brought to the starting frequency of the measurement, (2) its output is adjusted to the required level, (3) the connections mentioned are made, (4) the oscilloscope's settings (AC/DC coupling, Y- sensitivities, time base, trigger type (external, triggered) and trigger level are all adjusted so that steady waveforms are obtained with a few whole cycles fill the screen without being clipped. This procedure, by freeing the program from a potentially long scaling/rescaling procedure saves time and guarantees a successful measurement.

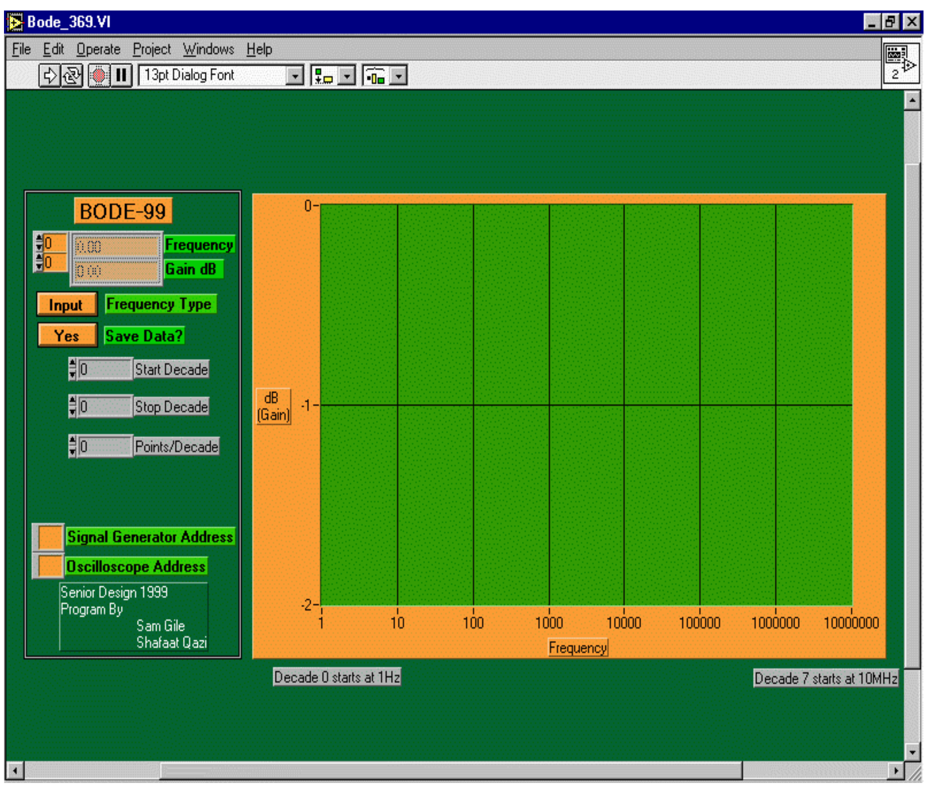

Figure 2. Bode-99 Graphical User Interface

Bode-99 initially displays the graphic interface screen shown in Figure 2 for the user to specify the range of the frequency sweep, "StartDecade", "StopDecade", "Points/Decade". The integer number selected stands for the power of 10, i.e., 1 means 10 Hz, 6 means 1E6 Hz = 1MHz. The user has the option of asking the program to generate a text file containing the data. The user also has the option of requiring the code to measure the frequency from the waveform versus assuming the signal generator generated the waveform at exactly the frequency value the code has sent as a command to the signal generator. Typically digital signal generators are very accurate. Therefore, this option is not chosen to avoid unjustified lengthening of measurement time. However, with poorly calibrated signal generators, or older analog generators with external voltage controlled frequency, this option becomes essential.

The graphical display of the frequency response is auto-scaled and renewed after each and every new data point is acquired. The numerical values of the frequency measured and the gain value (in dB's) calculated from the last (current) measurement are also displayed in the upper left corner.

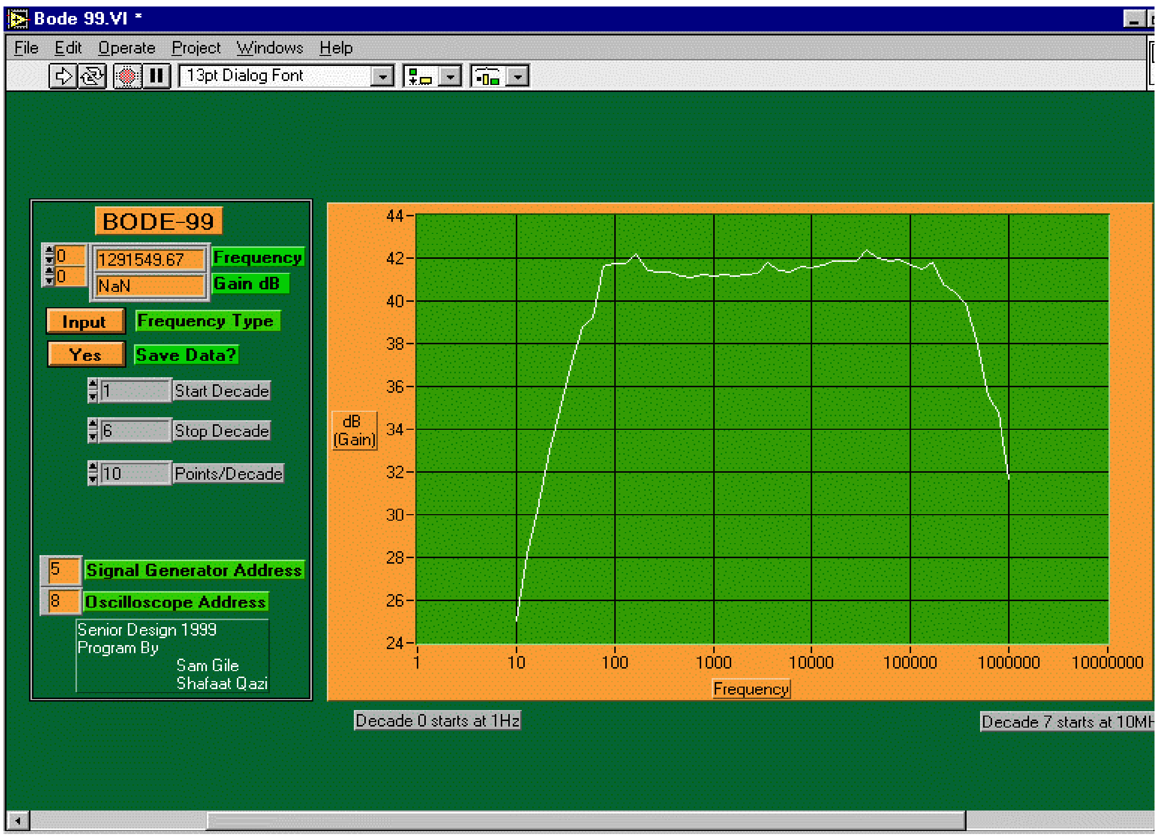

Figure 3: Frequency Response of a 3-Stage BJT Audio Amplifier Displayed in LabView

Bode-99, calculates the spot values of the frequency at the current step by using logarithmic increments corresponding to the "Points/Decade" value entered by the user. This assures evenly distributed data points on Bode magnitude or Bode phase plots. For each and every frequency step, input and output waveforms are displayed on the oscilloscope screen. In order to avoid imprecision or inaccuracy, former caused by too small a vertical deflection on the 8-bit resolute screen, the latter caused by clipping of the waveform due to overranging of the A/D converter, Bode-99 program uses an algorithm to scale the vertical sensitivity up or down to keep the waveform within 20% to 80% of full vertical range. Similarly, for the accurate measurement of the full period (needed for frequency and phase calculations) and for delay measurements (needed for phase calculation), the horizontal span of the screen (10bits) should fit a few whole cycles but not too many. Bode-99 has an algorithm to set the time scale of the oscilloscope to fit 3 to 5 full cycles of the waveforms. This routine employs the calculated current value of the frequency to calculate and pick the right horizontal scale. If the program cannot fit the waveforms into one screen after 10 attempts, it pauses and asks for manual interference.

The automated frequency response measurement system described hereto has been used in characterizing active/passive filter circuits and amplifiers designed in the junior electronics laboratory and in the evaluation of the gain-bandwidth performance of student designed CMOS operational amplifiers which were fabricated through MOSIS. The system was built and the programming was done as a part of senior electrical engineering capstone project at the University of Southern Maine. Figures 3, 4, and 5 shown in the remaining pages give results obtained with two different circuits, (1) a JFET-input AC-coupled Three-stage BJT audio amplifier designed in junior year Electronics II laboratory, and (2) an inverting 10X gain amplifier constructed from a NMOS-input CMOS operational amplifier. The CMOS operational amplifier was designed as a part of ELE 444 Analog Integrated Circuits class, and sent out to MOSIS, fabricated and packaged. The 10X amplifier was built as an application of the CMOS amplifier as well as demonstrating its functionality and determining its Gain-Bandwith product.

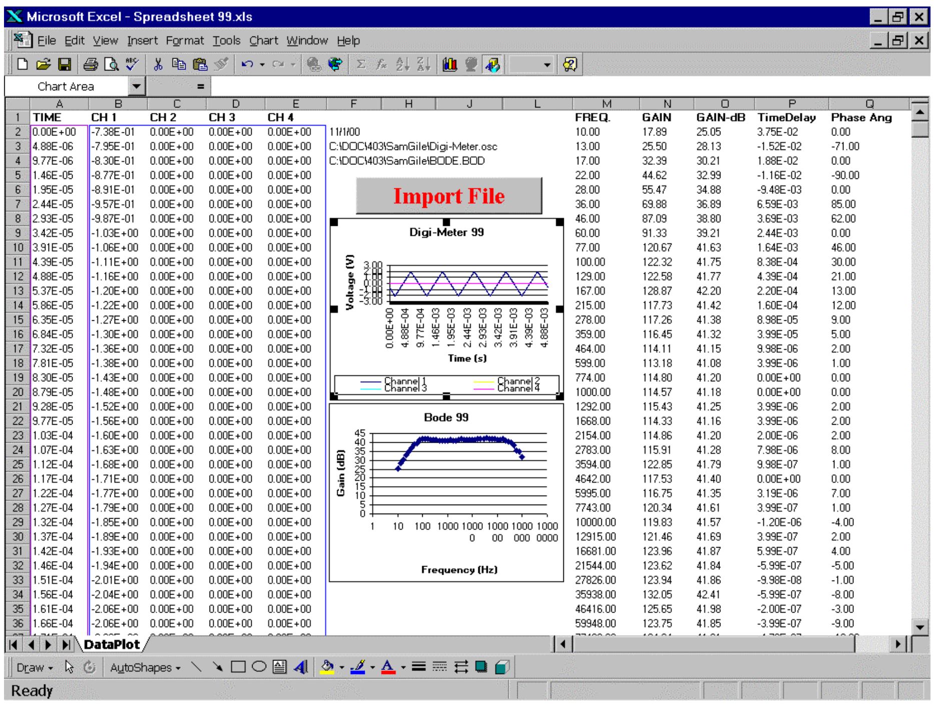

Figure 4. Frequency Response and Waveform Data Captured and Displayed in Excel.

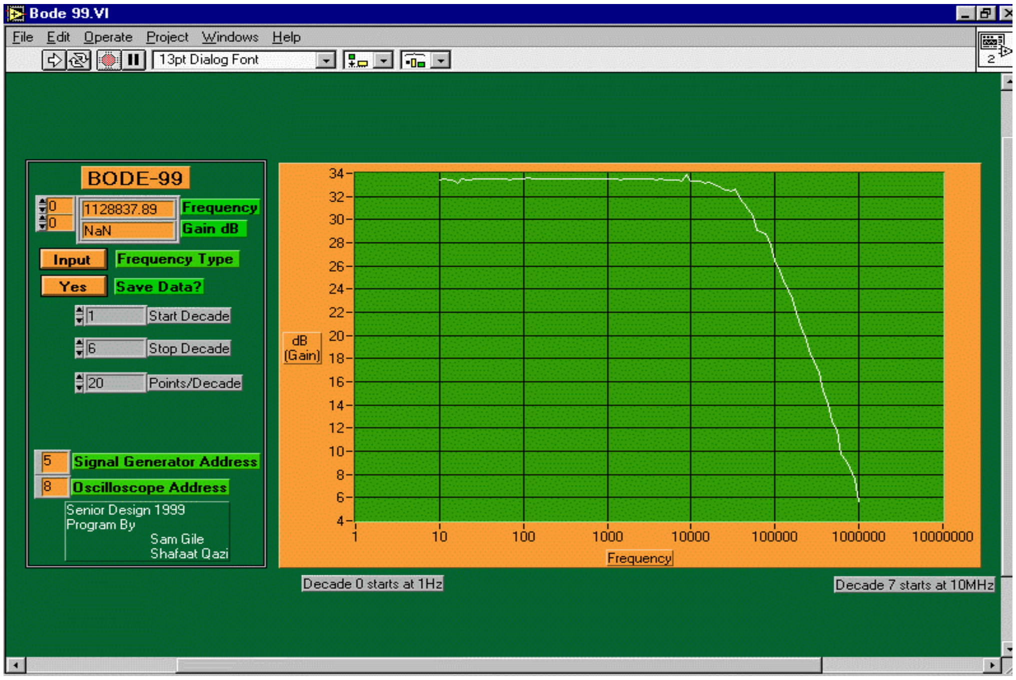

Figure 5. Frequency Response of a MOSIS Fabricated CMOS OpAmp Amplifier (Displayed in LabView)

3. Conclusions and Remarks

The system was built and the programming was done as a part of senior electrical engineering capstone project at the University of Southern Maine. It has been used in the characterization of the frequency response of single- and multi-stage amplifiers, operational amplifier circuits, passive- and active-filters designed and tested in junior year Electronics I & II laboratories. The set-up was also used in measuring the frequency response of amplifiers built from CMOS operational amplifiers which were designed and sent out to be fabricated at MOSIS. These latter measurements are used to determine the Gain-BandWidth product of these internally frequency compensated operational amplifiers. It should be noted that the set-up and the code developed can easily be adapted to measuring the frequency response of electromechanical and non-electrical (such as acoustical) systems with the addition of appropriate transducers and sensors. One important application would be to determine modal frequencies of mechanical structures and do vibrational analysis similar to the one given by Walsh and Orabi [4].

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